lished by the same eminent authority in 1894. A new reduction of Taylor's 11,015 stars is expected soon to appear from the Nautical Almanac Office of England. Thus the most important old catalogue which needs to be newly reduced is Piazzi's: and the object of my remarks has been to show that at the present moment a vast amount of the work incident thereto *is already accomplished.* Thanks to the generosity of Miss Catharine W. Bruce, of New York City, financial assistance was rendered for the employment of computers between June, 1898, and January, 1900, whereby much of this result was attained. But now the possibility of its completion rests not so much in the faithful persistence of those engaged in the computations as in the additional generosity of other patrons of astronomy, and in the continued encouragement which so many Observatories and individual astronomers have thus far seen fit to so kindly bestow.

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SCIENTIFIC BOOKS.

Scientific Papers. By JOHN WILLIAM STRUTT, Baron Rayleigh, D.Sc., F.R.S. Vol. I., 1869–1881. Cambridge at the University Press. 1899. Quarto, pp. i–xv., 1–562. New York, The Macmillan Co. Price $5.00.

In endeavoring to review this first volume (1869–1881) of the researches of an author like Lord Rayleigh, who has contributed fundamentally to whatever he has undertaken, and who speaks authoritatively on almost every topic in physics; in whose work, in other words, both the quality and the quantity are in evidence, it would be rash to attempt to give more than an outline of the contents. The papers moreover, are in general too severely difficult to be read as a whole, and there are no figures or diagrams (or almost none) to assist the imagination, no italics to stimulate curiosity. Many of the papers are theorems in pure mathematics, but in few cases (contributions to the mathematical tripos examinations, for instance) is the mathematical story left unadorned by the moral of an application. Lord Rayleigh is pre-eminently a physicist, and mathematics with him is good means to a better end.

The book opens (1869) with papers on the applications of dynamics to electro-magnetic phenomena, showing the influence of the inspiration of Maxwell and worked out along Maxwell's lines. Thus the analogy between the decomposition of water, produced or not produced according as the circuit of a Daniell's cell (alternately made through a shunt and broken through the electrolyte) contains a coil or not, and the action of an hydraulic ram, the analogy between the spark and the rupture of the pipe, etc., are all in the spirit of an accentuation of Maxwell's conception of electric inertia, long before Lodge had popularized that doctrine. The investigation leads to a consideration of circuits containing self induction and capacity, and is carried through two long papers largely experimental in character and similar to Henry's researches on the magnetization produced by oscillatory currents.

Then follow two papers on acoustics beginning a subject destined to culminate in 1877 in the well known work on sound, which like de St. Venant's elastics, has remained without a compeer. The shorter paper completes Sondhauss's theory on the influence of the size and the form of flasks on the sounds produced when a current of air is blown across their mouths, with the aid of Helmholtz's famous research on the vibration of open organ pipes. The longer is the great paper on the theory of resonance, published in three parts in the *Philosophical Transactions* of 1870. Rayleigh here also begins with Helmholtz's results for 'Hohlräume,' using a parallel but thoroughly different mathematical treatment. Part I. contains the general dynamics for resonators of small dimensions compared with wave length, and communicating with the air by any number of holes or necks, usually along an infinite plane, and a final application to the open organ pipe is sketched out. Part II. is devoted to the special problems relating to necks, etc., suggested in Part I. The neck is here considered relative to its 'resistance' to vibration, and the pertinent electrical analogy is used

throughout the discussion. In part III. the theoretical deductions are verified by experiment for such cases as admit of accurate numerical computation. Much of this theory is embodied in the second volume of 'Sound' (16th Chapter).

After this Lord Rayleigh's mind seems to have been intensely attracted by optical phenomena, and we find first a critical examination of Verdet's diffraction theory of the solar corona, followed by a long experimental paper confirmatory of Maxwell's theory of color perception. The experiments aim at establishing the linear equation between any four colors with a higher degree of accuracy. They are made with Maxwell's educationally now very familiar color wheel. In 1871 came the two papers dealing with the dynamics of the blue sky, perhaps the most famous of Lord Rayleigh's theoretical researches. It is needless to refer to them at length here, since an easily intelligible presentation is given in Preston's theory of light (Art. 162). If the long waves are absorbed on transmission and the short waves scattered, the blue color of the sky is naturally a manifestation of the surviving mean wave lengths. Clausius, it appears, had previously developed an interferential theory to account for the same phenomenon at considerable length, but had subsequently rejected it chiefly because in the case of particles small in all their dimensions as compared with the wave length of light the ordinary laws of reflection no longer hold and an independent investigation is imperative. Without being aware of these misgivings, Rayleigh took up and completed the subject from the point where Clausius * left it. The former has frequently recurred to the same investigation, showing in a recent paper, for instance, that scattering may even be promoted by the molecules of air themselves.

* To me it seems probable that these researches of Clausius may be resuscitated in relation to the colors of cloudy condensation. As seen in the color tube by transmitted light, the yellows, oranges, browns, of the first order, ending eventually in opaque are undoubtedly Rayleigh's colors. The jet in reflected light is bluish. Beyond this, with increasing size of particles, the transmitted colors are violet, blue, green, yellowish, purple, etc., following Newton's color series, and to these, it would seem, that Clausius's investigations are applicable. I shall return to this interesting subject elsewhere.

Of the two optical papers which follow, the first, a theory of double refraction based on the hypothesis of difference of molecular inertia in different directions (given for instance by the case of a disc vibrating in a resisting fluid), seems to have been disproved shortly after in experiments of Stokes's. The other is an elaborate contribution to Fresnel's fundamental investigation on the intensity of light reflected from transparent media. Fresnel's expressions have been remarkably suggestive, and they are approximately true. The method by which the tangent formula is derived, however, is not rigorous, and he was of course unaware of Jamin's discovery of the change of phase which accompanies reflection. Green's, Cauchy's, MacCullagh's, Neumann's, and Lorentz's theories are successively examined, but the nature of the correction (Fresnel's result predicts extinction at the angle of polarization), or a derivation which shall satisfactorily dispose of the longitudinal wave is not ascertained. All this recalls Lord Kelvin's Baltimore lectures. A subsequent paper on the reflection of light from opaque matter is much along the same lines, being critical rather than constructive. It is curious that a man of Rayleigh's genius instead of wrestling with these abstruse elastic theories did not make an entirely new departure from the basis of the electromagnetic theory* of light, as did afterwards Helmholtz in his famous paper on dispersion.

At about this time the reproduction of diffraction gratings by photography, a fascinating subject engaged Lord Rayleigh's attention, and as in most of his work, grew eventually into an extended treatment of the degree of perfection attainable in gratings. Transparent gratings of Nobert, with 3000–6000 lines to the inch were found directly reproducible when used as negatives, and the copies proved nearly equal in quality to the original, showing for instance, the nickel line between the D's. Gelatine reproductions (obtained by the photolithographic process with chromate of potassium)

* Although Maxwell's electricity was not completed until 1873, one would suppose that the contents could not be quite unknown to Rayleigh.

surpassing the Nobert plate in brilliance also succeeded. Since to resolve the D lines the distance between the rulings must be true to 1/1000, this performance seems incredible. Yet Rayleigh anticipates no limit to his method up to 10,000 lines to the inch. Copies of similar gratings made in accordance with Rayleigh's directions are found in most of our laboratories. They have not held their own owing to the enormous stride forward in diffraction spectroscopy due to the invention of Rowland's concave grating. Connected with these papers is one on the diffraction of object glasses in telescopes, in which the advantage of a central stop to cut off superfluous light without destroying the definition is succinctly laid down.

Of Lord Rayleigh's highly important contributions to mathematical literature made at about this time, bare mention only is possible here. A paper on some general theorems relating to vibrations deals with great breadth of method with the reciprocal character of forces and motions of any two types. To quote an illustrative example: If A and B are two points of a stretched string, a periodic transverse force at A produces the same vibration at B as would have ensued at A for a force acting at B. Another paper treats of the numerical calculation of fluctuating functions (Bessel functions, for instance, though the method has broader scope) when the usual expansions in series fail. Again the reciprocal properties of systems capable of vibrating about a position of equilibrium, is accentuated in a further paper put in form of a statical theorem. Of these powerful theorems (together with a parallel theorem of Helmholtz) Rayleigh frequently makes effective use, and reference to them occurs in other parts of the volume, either in relation to sound or to light. Finally, the proof of Thomson's theorem, that if a material system start from rest under the action of given impulses, the energy of the actual motion exceeds that of any other which the system might have been guided to take under the operation of constraints, etc., is recast in such a way as to suggest important corollaries.

Two papers on thermodynamics now appear. It is Rayleigh's idea to utilize the fall of temperature between the furnace and the boiler as well as that between boiler and condenser by supplementing the steam engine with an auxiliary oil engine, and the development leads to a discussion of the doctrine of dissipation. Again the case where work may be gained by mixing gases, as for instance when hydrogen diffuses into air through a porous plug, is subjected to computation, by finding the work needed to separate a mixture. The line of reasoning adopted by Lord Rayleigh in this paper reminds one of the fundamental research of van't Hoff, though it breaks off with the isolated case under discussion. The interesting result is formulated that relatively more work is needed when the ingredient to be separated is present in small quantity.

At this point we come upon a series of distinctively hydrodynamic researches, beginning with a paper on gravitational waves. The case of the long wave in shallow water was solved by Lagrange, who showed that its velocity is identical with that of a heavy body falling half the depth of the canal. If the water itself moves with an opposed velocity, the wave form is of the steady type often observed in gutters conveying water. After enlarging the theory of long waves, Rayleigh applies it to find the effect on a stream of a contraction or a widening of the channel, to the case of the solitary wave (for which he finds a theoretical explanation agreeing with Scott Russel's observations. The solitary wave when positive, *i. e.*, an elevation, has considerable permanence. The negative wave on the contrary soon breaks up), to periodic water waves and to the oscillations of water in a cylindrical vessel.

This research is followed shortly after by an investigation of the resistance of fluids. Helmholtz had previously pointed out that finite slipping was left out of account on ordinary hydrodynamics. Rayleigh is induced to reopen the subject with the ulterior object of formulating the resistance encountered by a solid body floating in a stream. In the case of a plate it appears that the resistance to broadwise motion can be increased enormously by the superposition of an edgewise motion, a result of great value in aërial navigation. It recalls the striking results obtained by

Langley in the same direction. In a further paper the theory of the vena contracta and of colliding jets is subjected to analysis, in which (following Maxwell) the inferences are drawn directly from the principle of the conservation of linear momentum. To the question of jets, Rayleigh returns in succeeding papers. In the first of these the conditions of instability are discussed, both for capillary or statical instability, and for dynamic instability, such as occurs, for instance, in waves or surface of water under the influence of the wind. The other paper examines the capillary phenomena observed in jets issuing from an orifice which is not circular, but elliptic, triangular, etc. Apart from form, the wave lengths of the issuing stream have a close relation to the square root of pressure. Disposing of this case, Rayleigh then passes to the dismemberment of the circular jet into drops, or of an oblique jet into sheathes, using the experimental (shadow) method of Buff. A curious result of the analysis may be mentioned, viz, that the radius of the sphere which vibrates capillarly in seconds is about one inch. Rayleigh's more recent work with jets and ripples is not included in this volume, but interspersed among other hydrodynamic researches is the fascinating and well-known paper on the influence of electricity on colliding water drops, proving that whereas unelectrified drops rebound on collision, electrified drops coalesce. The conclusions are made more striking by the examination of paired jets, and an important inference is drawn relative to the growth of rain-drops stimulated by thunder storms. A further paper on the instability of fluid motions (the preceding cases being chiefly of interest in their relation to sensitive flames and smoke jets) reopens the whole question, obviating the preceding hypothesis of discontinuous fluid motion and admitting only such gradual changes of velocity as must inevitably occur in viscous liquids. A final paper is devoted to progressive waves, treating the case frequently observed that the group velocity of waves advancing into still water is often below the velocity of the constituent members of the group. The investigations are largely embodied in 'Sound.' They are referred to the case of two infinite wave trains of the same amplitude and nearly the same wave-length, superposed.

Meanwhile Lord Rayleigh has not lost interest in acoustical subjects. In a paper on our perception of the direction of a source of sound there occurs a humorous passage which is rare in his writings. "The efficient action of a lens" (for the purpose in question) "depends on its diameter being at least many times greater than the wave-length of light, and for the purposes of sight there is no difficulty in satisfying the requirement. The wave-length of the rays by which we see is not much more than a ten-thousandth part of the diameter of the pupil of the eye. * * * The waves of sound issuing from a man's mouth are about eight feet long, whereas the diameter of the passage of the ear is quite small, and could not well have been made a large multiple of eight feet." Usually the imputation of ears longer than 8 inches is regarded sufficiently undignified to be resented.

A similar paper with acoustical observations relating to binaural audition, reflection and interference of sound, pitch, etc., follows. Rayleigh then contributes to the few data then known of the amplitude* of the audible sound wave, by computing it roughly from the energy needed to blow a whistle and the distance of audibility, using a straightforward method which, like many others in the volume ought to find its way into our text-books. He finds the observed amplitude to have been of the order of $1/10^7$ centim., but believes the 1/40th part of it to be audible under favorable conditions. A paper on absolute pitch is concerned with the discrepancy observed between König's and Apunn's tonometers, which Rayleigh attributes to the mutual influence of simultaneously sounding reeds. He proposes a tuning fork clock method of his own. Another paper relating to Mayer's phenomenon of acoustic repulsion shows the pressure within a resonator to be in excess of atmospheric pressure, which is equivalent to a force at the mouth of the resonator directed normally inward. Then comes an original explanation of

* With the invention of Professor Webster's interferential apparatus this dearth has already become fruitful.

the effect of external influences in modifying vibrations, the former being grouped into such influences as modify pitch and those which encourage or discourage vibration. Thus in the latter case, an impulse would have to actuate a pendulum while passing through its position of equilibrium; in the first case the impulse must be applied at either elongation. The principle is illustrated in its bearing on the sounds frequently obtained in glassblowing, on the chemical harmonica, and on other similarly subtle methods of sound production. A second paper on absolute pitch accentuates the fact that two equations are given when the frequency-ratio and number of beats per second of two notes of a selected interval are given from which the absolute pitch of both may be computed. The inferences are tested with modifications by aid of the common harmonium. A new series of acoustic experiments deals with the production of pure tones from sounding flames on suitably modifying the resonator, with Savart's region of silence on reflection, with sensitive flames (which seem to fascinate Rayleigh as they did Tyndall and by which the remarkable investigations on jets above referred to were suggested), etc. Among the results we find that sensitive flames are excited at loops and not at nodes, that Rijke's notes (produced by heated gauze on cooling in a pipe) can be raised to an intensity sufficient to shake a room. Experiments are given on the effect of a barrier in promoting interference between the two halves of an organ pipe. In an ingenious experiment in which the chimney is made available as a source of draft, it is shown that the vibrations of the strings of an Æolian harp are at right angles to the direction of the wind. A final series of acoustic observations begins with the full discussion of Mayer's well-known experiment on intermittent sounds. After showing a new form of siren, an experiment is described for obtaining the interferential sound shadow of a circular disc, an analogue of the optical experiment. The last acoustical paper included is an explanation of the photophone.

The remaining papers of the volume are largely devoted to optics. We notice in particular a long and frequently quoted paper (1879–80) on the resolving power of telescopes with especial reference to spectroscopy.* Starting from the deductions of Airy, Verdet and others, Rayleigh computes the visibility curves for single and double lines, single and variously doubled slits. In an examination of the prismatic spectroscope it appears that the resolving power for a given glass is proportional to the total thickness traversed without regard to the number, angles or settings of the prisms. The aberration errors and the degree of accuracy required in the surfaces are abstrusely treated in detail and a final paragraph is devoted to the designing of the spectroscope. A subsequent theoretical paper deals with reflection when the transition at the boundary of two media is gradual and not abrupt as usually assumed by the great opticians (Fresnel, Green, Cauchy and others). Passing this and an experimental method (grating) of measuring the resolving power of telescopes, as well as another on the definition of images formed without lenses, we come to Rayleigh's first considerable papers (1881) on the electromagnetic theory of light. It would appear from this that Rayleigh like Kelvin was late in his acceptance of Maxwell's optics, certainly a regrettable circumstance by which the advance of science was retarded. It is the object of the present long investigation, to find an electromagnetic basis for Fresnel's optics, particularly in relation to reflection and to double refraction. In different ways Hemholtz, Lorentz, J. J. Thomson and others have all worked successfully at this problem. It is well known that to explain double refraction Fresnel postulated differences of rigidity of the ether in different directions; to explain reflection such a change of rigidity in passing from one medium to another is precluded. Neumann and MacCullagh have endeavored to obviate the inconsistency by replacing differences of rigidity by differences of density, but the elastic theory resulting is none the less imperfect. The electromagnetic theory of light based on radically different laws avoids these discrepancies at the outset. Naturally in Rayleigh's work the scattering reflection of moats is particularly considered as a test of

* In America, as we know, similar work has been remarkably promoted by the researches of Professor Michelson.

the equations deduced. In a following paper discussing Young and Forbes' experiments in which the velocity of violet light apparently exceeds the velocity of red light by 1.8 per cent., Rayleigh again accentuates the difference between the group velocity and the individual velocity of waves. The last optical paper in the volume reopens the question relative to the production of a truly compound yellow made of red and green, and treats other questions of similar psychological interest. The concluding paper of the book is an investigation in pure elastics, dealing with the infinitesimal bending of surfaces of revolution, with particular reference to the theory of bells.

I am of course well aware that the account which I have endeavored to give of this great book is altogether inadequate; but with such an exuberance of material, and so much of it expressed either in untractable equations or in a style admitting of expansion only, all attempts are foredoomed. Besides the larger papers which I have mentioned, there is a bewildering array of smaller articles, sententious criticisms or suggestions mathematical or not, theorems, special solutions, computations, etc. Some of Lord Rayleigh's most helpful services to science are to be found in these current notes and as a rule they are hard to find. For this reason the present complete republication of his works is additionally to be welcomed.

Rayleigh's style is exquisitely terse. Even those papers which are free from mathematics are not easy reading. The endeavor to make a clear statement more intelligible is rarely thought worth while. The greater number of papers are short. The average 7 pages each (78 papers in the 562 pages of this first volume). Withal it is a book to which one may come for fundamental originality, but one must expect to pay for the privilege. It is pleasant to note that Rayleigh cheerfully gives credit to the labors of others and not only to those of his own nation. But however genial his criticism it is none the less keen. Errors are virtually dismembered with a few deft strokes, and the incident passes before there is time to cry for mercy. On the whole a wise man will think twice before he disagrees with the author of these 'Scientific Papers.'

Lord Rayleigh is not quite as radical as some of the other English mathematicians in eschewing formulated mathematics as far as possible, a method which those of us who do not aspire to become too mathematical for mathematics, cannot but regret—at least when we have practical occasions for following the argument. There is moreover something amusing about this fashion of verbally treating abstruse mathematical doctrine. Our host, as it were, receives us at his ease, quite unarmed, and discusses the most delicate matters with complete nonchalance. But nobody is deceived. One may be quite sure that a strong man, armed cap-à-pie, is hidden away somewhere in the closet. When mathematics becomes verbal one feels that she is speaking a foreign tongue and that something is actually being translated. The original would be far preferable.

On closing the book one can not but wonder how much talk could be made out of a single page of it; or perhaps more graciously, how immensely science would be benefited if the bulk of what is now rampant were to shrink to the standard of Lord Rayleigh's text.

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System der Bakterien. By PROFESSOR W. MIGULA. Handbuch der Morphologie, Entwickelungsgeschichte und Systematik der Bakterien. Bd. II. Specielle Systematik der Bakterien. Jena, Gustav Fischer. 1900. Pp. 1068, pl. 18, figs. 35.

The working bacteriologist has long been in need of some treatise that would enable him to trace to the original description at least a fair proportion of the 'species' and 'varieties' that he finds referred to in the literature of the day. It is one of the great stumbling-blocks in bacteriology that a bewildering multiplication of names and synonyms has taken place during the last decade and has had its natural result in an almost hopeless confusion of bacteriological classification and nomenclature.

The great task essayed by Professor Migula may well command respect and admiration. Not only is enormous mechanical labor involved in the extracting and collecting of 1200